James Acker:
Cecile provided me with a LOT of text, so I'll move fairly quickly.

Feel free to tell me to slow down a little.

{Because the text was provided by Cecile Rousseaux, her name appears below.

Cecile Rousseaux:

In this presentation I will show you how data from a biogeochemical model (NASA Ocean Biogeochemical Model, NOBM) available on Giovanni have helped us improve our understanding of the effect of climate variability on phytoplankton composition in the Pacific Ocean.

All phytoplankton contain chlorophyll a, a pigment that allows them to convert light energy into carbon which then can be transferred to higher trophic levels. By using ocean color data, we have been able to estimate the chlorophyll a concentration at large spatial and temporal scales.

From this we have learned that during El Niño events, when the upwelling off South America is suppressed, chlorophyll a concentration decreases (represented on the ocean color image that you see on this slide). During La Niña events on the other hand, the upwelling is restored and the chlorophyll concentration in this region increases (see bottom figure).

During the 1997-98 El Niño event, one of the strongest El Niño events observed by Ocean Color data, the phytoplankton concentration, represented by chlorophyll, decreased in the Equatorial Pacific and the associated Peruvian anchovy fishery collapsed (see figure).

The generalized mechanisms for these events are well described: wind reversal during El Niño leads to reduced upwelling in the eastern tropical Pacific, impacting total phytoplankton concentration and the fisheries that depend upon them.

Each phytoplankton taxa thrives under specific physical and chemical conditions and have their own biogeochemical functionality. Diatoms, for example, require the presence of nutrient-rich conditions and support a relatively short food chain that leads from phytoplankton to zooplankton to fish.

On the other extreme, cyanobacteria can survive in low nutrient conditions and support a food-web that relies more heavily upon recycled nutrients, has a high turnover, and where bacteria and picophytoplankton are consumed by protozoa, ciliates and microzooplankton. Between these two extremes, a multitude of phytoplankton groups exist with a wide variety of responses to environmental changes. In the NOBM we have 2 transitional groups: chlorophytes and coccolithophores.

The question that we asked was whether "the decrease in chlorophyll that was observed using ocean color data resulted in the decrease of all phytoplankton groups, or whether it led to a shift in phytoplankton composition (some groups decreasing, and some others benefiting of the new conditions)?"

The model we used to answer this question is NOBM. This figure represents the interactions among the main components of NOBM, nominal input and forcing fields. The model comprises four phytoplankton groups (Diatoms, Chlorophytes, Coccolithophores and Cyanobacteria), four nutrient groups (Iron, Nitrate, Ammonium and Silica), a single herbivore group and three detrital components (Iron, Silica and Nitrogen/Carbon).

Carbon cycling involves dissolved inorganic carbon (DIC), dissolved organic carbon (not represented here) and pCO2. Radiative transfer calculations provide the underwater irradiance fields necessary to drive phytoplankton growth, and interact with the heat budget. It requires external monthly climatologies of cloud properties, surface pressure, wind speeds, relative humidity, precipitable water, and ozone (see Gregg, 2008 for more details).

Total chlorophyll fields (sum of all phytoplankton components) in NOBM are assimilated using Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data from 1998-2007. The assimilation produces chlorophyll estimates within 0.1% bias and 33.4% uncertainty as compared to in situ data, similar statistically to SeaWiFS and in situ data.

The bottom right figure shows an example of the daily satellite coverage with the absence of data between swaths (in black).

On the bottom left you have the monthly average and as you can see, data are missing in some areas such as the Antarctic where clouds during certain time of the year don't allow for sampling. By assimilating these data into the model (top left) we are able to have full daily coverage which represents a significant improvement.

The top right image is the free-run (without assimilation). This figure shows that the free-run and the assimilated version are comparable although the assimilation represents a considerable improvement in area such as the North Atlantic and North Pacific.

In the previous online data of NOBM we used a uni-variate assimilation. We have now updated it to a multi-variate assimilation for the following reasons. The assimilation of chlorophyll by nature changes the balance between the chlorophyll-containing phytoplankton and the nutrients needed to support them. Most of the time the imbalance is small and is corrected by the interaction of the physics and biology in the model.

However, sometimes this imbalance can be important, especially in regions where the chlorophyll assimilation is a persistent adjustment to a persistent model bias. This is observed in the South Pacific where the model produces higher chlorophyll than the satellite observes, and there is high concentration of nitrate in the deep waters (see figure).

The assimilation of chlorophyll reduces the concentrations, resulting in reduced nitrate uptake, and leading to excessive nitrate arising from deep water to the surface layer. In a multi-variate assimilation methodology, these imbalances derived from the assimilation of satellite chlorophyll are corrected using a mechanistic approach involving the nutrient-to chlorophyll ratios embedded in the model.

The difference between the chlorophyll assimilation results and the prior chlorophyll produced by the model (the analysis increments) are used to adjust the nutrient concentrations. The multi-variate assimilation is applied to silica and dissolved iron, as well as nitrate.

So, getting back to our question of whether El Niño events resulted in a decrease of all phytoplankton groups or in a phytoplankton composition shift: we found that most of the effect of climate variability on phytoplankton composition was found in the Equatorial Pacific.

On the top panel of this figure you can see the temporal variation in chlorophyll (red) and nitrate (black) concentration between 1998 and 2008. The gray bars represent the Multivariate El Niño Index (MEI). Note that linear trends and seasonal climatology are removed to highlight the interannual variability which is the emphasis here. The seasonal mean is added back to produce representative chlorophyll concentrations as opposed to anomalies. The effect of the 1997-1998 El Niño on chlorophyll concentration is very clear on both the nitrate and chlorophyll concentration. In terms of phytoplankton composition, the second subplot on this figure shows that diatom concentration was low during the 1997-1998 El Niño, when nitrate was low, and increased after this event.

At the same time, cyanobacteria concentration was at a maximum during the 1998-1998 El Niño suggesting a phytoplankton community shift during El Niño event. Subsequent El Niño events, although less intense, had also an effect on the phytoplankton composition (e.g. 2002-2003, 2005, 2007). On the third subplot of this figure, the temporal variation in chlorophyte and coccolithophore concentration is represented. These two groups were clearly more intermediate in their response to climate variability and statistical analysis is required to see whether there was any relation between their concentration and climate variability.

The tropical and sub-tropical phytoplankton communities exhibited a wide range of responses to climate variability, from radical shifts in the Equatorial Pacific, to changes of only a couple of phytoplankton groups in the North Central Pacific, to no significant changes in the South Pacific. In this table, bold numbers that have a '*' after them means that the correlation was SIGNIFICANT.

In the Equatorial Pacific, there is a negative correlation coefficient between diatoms (and chlorophytes, although not significant) and climate variability.

Cyanobacteria and coccolithophores, on the other hand, were positively correlated with climate variability. In contrast to the Equatorial Pacific, the relationship between MEI and phytoplankton composition was more subtle in the North Central Pacific Ocean and nonexistent in the South Pacific.

The spatial effect of climate variability on phytoplankton community composition showed radical shifts. The spatial pattern shifts were especially notable for the phytoplankton functional extremes, diatoms and cyanobacteria. During El Niño events, when nutrients were limited, cyanobacteria were predominant in the tropical Pacific Ocean. Diatoms, in contrast, were restricted to the eastern portion of the Equatorial Pacific.

During La Niña events, when the upwelling was restored and nutrients replenished, diatoms expanded westward to the date line along the cold tongue while cyanobacteria retreated to the gyres and the extreme western portion of the tropical Pacific

As shown in this idealized conceptual diagram, the distribution of chlorophytes and coccolithophores also varied with climate variability although to a lesser extent when compared to diatoms and cyanobacteria. During La Niña, chlorophytes were distributed to the immediate north and south of the equatorial cold tongue and coccolithophores occupied the western edge. During La Niña events, coccolithophores occupied the western edge of the cold tongue.

James Acker:
JGA note: should be able to see this in PIC data in Giovanni.

Cecile Rousseaux:
During El Niño, coccolithophores expanded eastward along a narrow band in the Equatorial Pacific. In the model, the eastern Equatorial Pacific was where nutrients begin to become depleted, therefore giving way to coccolithophores because of their ability to grow in areas where nutrients and light were low enough to inhibit growth by diatoms and chlorophytes, but where there was insufficient vertical mixing to prevent their sinking losses, or where they could find nutrients at depth under low illumination levels.

The phytoplankton groups in the model have been validated against in situ data (publicly available at the Global Modeling and Assimilation Office (GMAO) web site, gmao.gsfc.nasa.gov. This data set includes 469 surface-layer observations of phytoplankton group abundances (full list of references available in Gregg & Casey, 2007). The data are converted when necessary into percent abundance of the entire population to compare with the model.

In our validation, we match up model mixed-layer relative abundances with the location and month of the in situ observations. We assemble all of these co-located, coincident match-ups over ocean basins, and over all the months for a year. We then average these match-ups over the basin annually. This provides us an opportunity to observe the large scale spatial performance of the model while keeping a close model-data relationship.

For the sub-tropical and tropical Pacific basins studied here, the phytoplankton relative abundances are always within 37% (absolute difference in relative abundance) of the in situ dataset in the 12 possible cases (4 phytoplankton groups in 3 oceanographic basins). Only 3 cases are >20%: a nearly ~33% underestimate of model chlorophytes in the South Pacific, a 25% model overestimate of diatoms in the South Pacific, and a 37% model overestimate of coccolithophores in the Equatorial Pacific.

These results provide a first line of evidence on how climate variability affects the phytoplankton community structure at a basin scale in the tropical and sub-tropical Pacific Ocean. The results here on the extent of the ocean biology response to climate variability (interannual variability) may have implications for climate change (long-term trends), considering recent results that the intensity and frequency of ENSO events may have increased in past warm periods [Scroxton, et al., 2011].

This suggests that the overall increase in cyanobacteria concentration and the decrease in the area where diatoms predominate during El Niño events may contribute to the decrease in fish stock and the collapse of fisheries such as the anchovies fisheries that was observed during the 1997-98 El Niño event [Chavez, et al., 2003]. Our results suggest that this change in the phytoplankton community composition during El Niño events does not occur over the entire Pacific Ocean but rather mostly in the Equatorial Pacific, locally in the North Central Pacific, and has negligible effect on the phytoplankton composition in the South Pacific.

James Acker:
That's Cecile's final slide and text. I'll leave this here for a moment in case you wish to get her email address.

Next week we will have a news item on the GES DISC home page about the new NOBM data. One of our presenters tomorrow, Sergey Piontkovski, is VERY happy about this.

Even though it is not real time, NOBM provides daily data in Giovanni.

We have a couple of minutes to rest our eyes, get out of our chairs, and be ready for Zhen Liu at 4 PM EDT.